HYBRID INTEGRATION OF LASER DIODE CHIPS ON A GLASS SUBSTRATE

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Abstract

An important task in optoelectronics is to realize optoelectronic transceivers in which a laser diode chip is hybrid integrated with an optical integrated circuit (OIC). In the paper, hybrid integration of Multi-Quantum Well (MQW) laser diodes with some integrated waveguide structures on glass substrate is presented. Coupling efficiency and overall performances are evaluated. Some remaining difficulties are discussed.

Integrated optical structures

The optical integrated circuits used in the experiments were a straight waveguide (Fig. 1) and an asymmetrical Mach-Zehnder interferometer, both realized on glass substrates. These waveguide structures were fabricated using a two- step silver-ion exchange technology. The ion exchange process was optimized in order to obtain embedded channel waveguides for reducing losses due to the light absorption of metallic silver crystals at the glass surface [1].

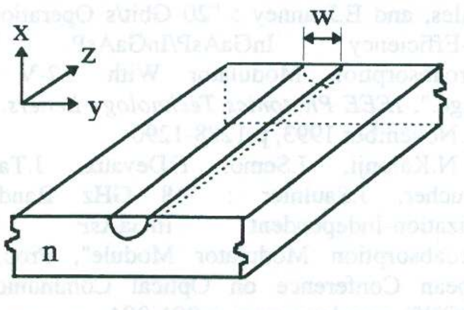

Fig. 1. Straight optical waveguide on glass substrate.

The straight waveguide was characterized by field pattern measurements using an image converter camera [2]. The measured image was further processed to get the mode profile. Fig. 2 shows the obtained near field pattern and the vertical distribution of optical intensity, displayed at the position of the marker line. In this case the mask opening was of 2 μm. The actual channel width in the glass substrate was around 6 μm due to the diffusion of ions. Using the same technology various OICs can also be produced including bends, Y-junctions, crosses and directional couplers [3].

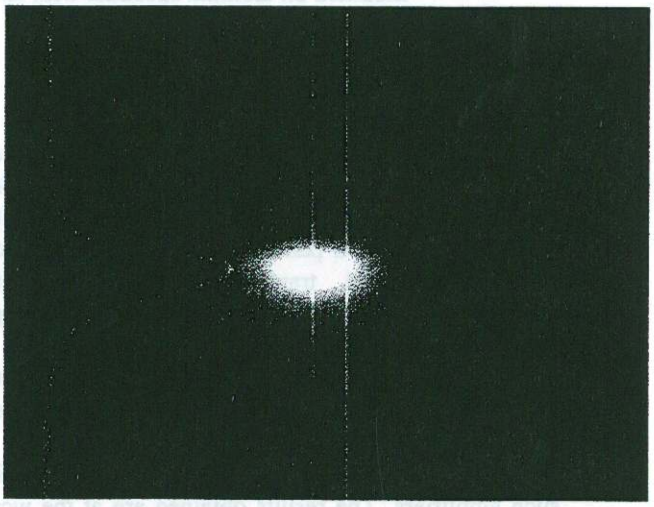

Fig. 2. Near field pattern of the realized straight waveguide measured at λ =1.3 μm. Vertical distribution of optical intensity along the marker line.

Several authors proposed to use optical fiber delay line structures to realize signal processing functions, for example frequency filtering [4,5]. However, signal processing at higher microwave frequency range requires very short delay line lengths with better precision. Therefore, optical integrated circuits seem to be an attractive solution [6]. Either unbalanced Mach-Zehnder interferometers (UMZIs), or optical ring resonators can be integrated on glass. The UMZI is realized by creating a path length difference (*ΔL*) between the two interferometer arms. This structure has a microwave frequency response with periodic rejections [7] :

$$f_{rej,k} = (2k+1)\frac{c}{2n_{eff}\,\Delta L}\,, \qquad (1)$$

where c is the speed of light, n_{eff} is the effective refractive index of the guide and k = 0, 1, 2, 3, ... However, several technological and measurement problems have to be considered in comparison with fiber systems.

Array of laser diode chips

The laser diode is an ultra high speed InGaAs/GaAs MQW Ridge-Waveguide (RWG) laser emitting at λ =1.1 μm. It is a part of a Fabry-Perot laser diode array with a cavity length of 200 μm. The width of the active channels of the chips in the array was w = 3, 4, 6, 8, 12, 16 and 40 μm, respectively. The typical optical efficiency of the laser diode is 0.25 W/A per facet. The optical intensity of two different elements of the same laser array, F7 1/6 and F7 2/6 having the same (w = 16 μm) channel width is plotted in Fig. 3 as a function of bias current.

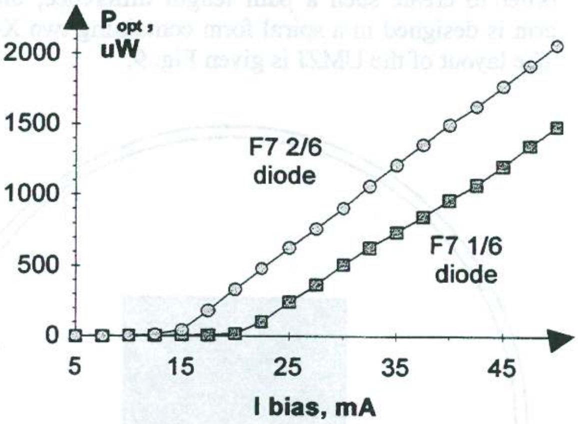

Fig. 3. Optical intensity vs. injected current.

The lasers have a low threshold current, typically around 15 mA. A typical optical power spectra of a MQW-RWG diode is plotted in Fig. 4. applying a bias above the threshold current. The side mode suppression ratio (SMSR) is better than 25 dB.

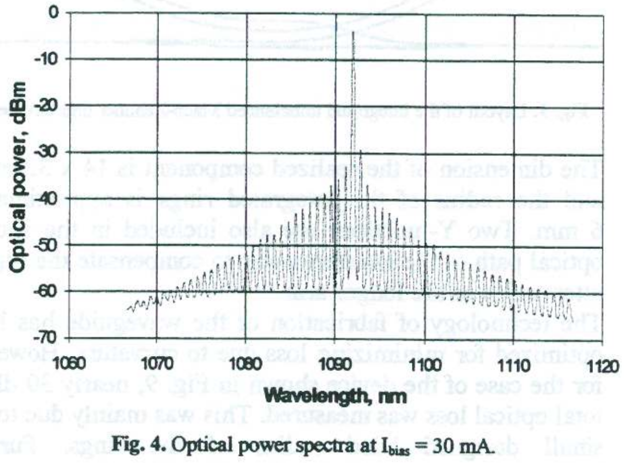

Fig. 4. Optical power spectra at I_{bias} = 30 mA.

To perform microwave functions, the laser diode is intensity modulated by direct modulation. The modulation response of the MQW-RWG lasers is measured up to 20 GHz by a Vector Network Analyzer (VNA), which is extended by a LightWave Test Set (LWTS). The coaxial electrical port of the S-parameter test set of the VNA is connected to a microwave probe having an air-coplanar contact, which fits well to the Ground-Signal-Ground (GSG) structure of the lasers.

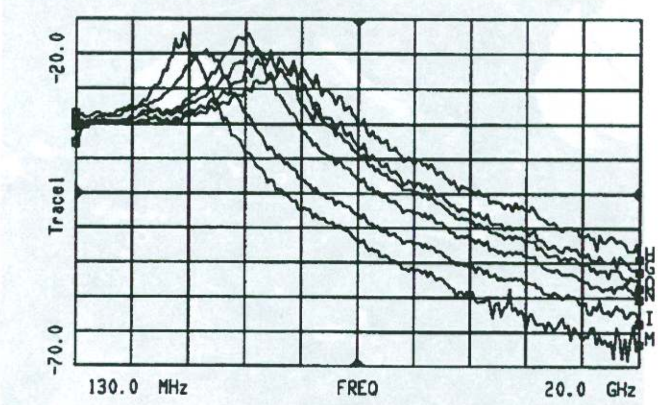

Fig. 5. Modulation response of a 16μmx200μm laser diode.

The microwave modulation signal is superimposed on the DC bias (inside the S-parameter test set) and fed to the laser diode through the microwave probe. Then the emitted light of the laser is coupled into the pigtail by using micropositioners and the monomode fiber is connected to the fast photodetector of the LWTS. The electro-optical NA is first calibrated to remove any error due to the frequency response of the LWTS photodetector. Fig. 5 presents a typical modulation response of the lasers as a function of bias current of a 16 μm channel width chip (I_{bias} = 25, 30, 35, 40, 45 and 50 mA, respectively). In the case of lasers having narrower channel width, the modulation bandwidth can exceed 20 GHz when the laser diode is biased at 50 mA [8].

Measured performances of the optical transceiver

The optical test bench used for testing the hybrid integration includes pigtailed monomode fibers, alignment micro-positioners, an air-coplanar microwave probe, VNA with its lightwave extension (LWTS), and an optical power meter, as it is shown in Fig. 6.

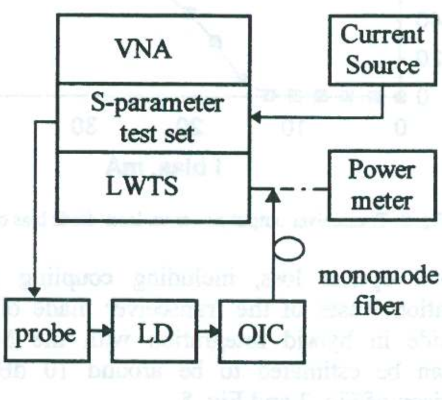

Fig. 6. Measurement setup.

The realized optical transceiver is made of the laser bar glued with the optical integrated circuit, as shown in the photograph of Fig. 7. For the integration, we used two component epoxy based glue to fix the OIC on the mechanical support piece.

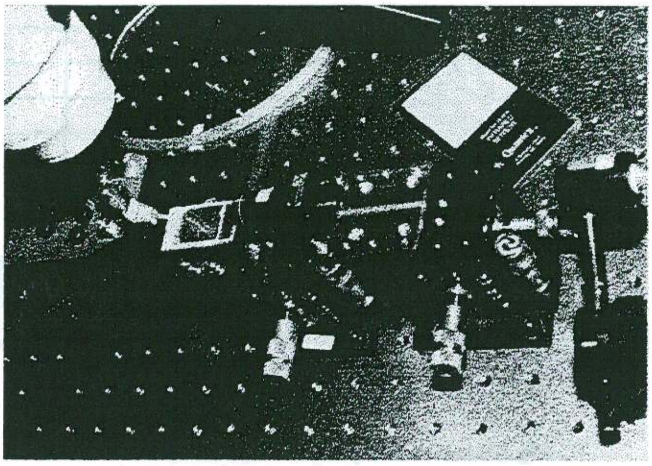

Fig. 7. Photograph of the experimental setup.

The measured frequency response of the integrated unbalanced Mach-Zehnder interferometer coupled to the laser diode will be given and discussed in the next paragraph.

The embedded channel guides are designed to operate at 1.3 μm, and they may have two or even three modes for light emitted by the laser diodes at $\lambda = 1.1$ μm wavelength. The OICs have linear propagation and bending losses, which were measured and taken into account to extract coupling loss. Fig. 8 shows the optical output power after the integration of the straight waveguide and the MQW-RWG laser diode.

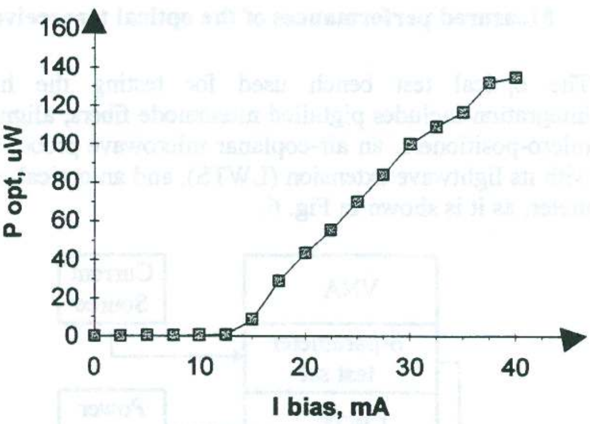

Fig. 8. Transceiver output power vs. laser diode bias current

The total optical loss, including coupling losses and propagation losses of the transceiver made of a straight waveguide in hybrid integration with the MQW-RWG laser can be estimated to be around 10 dB from the comparison of Fig. 3 and Fig. 8.

In this hybrid integration, the main source of losses was the coupling loss, approximately 5.5 dB. It is due to the mismatch between the near field distribution of the laser diode (vertically confined) and the mode size of the optical waveguide (approximately 8x6 μm^2). It is also due to the air gap between the polished facet of the glass waveguide and the laser facet (here approximately 50 μm). We are to improve this last point. Another improvement would be to fabricate laser diodes with tapers to enlarge the size of the field.

Microwave performance

An integrated unbalanced Mach-Zehnder interferometer was also connected to the MQW-RWG laser by butt coupling. This optical DUT acts as a microwave rejection filter with the first notch at around 2 GHz, which corresponds to a path length difference of ΔL=67 mm. In order to create such a path length difference, the longer arm is designed in a spiral form containing two X-crosses. The layout of the UMZI is given Fig. 9.

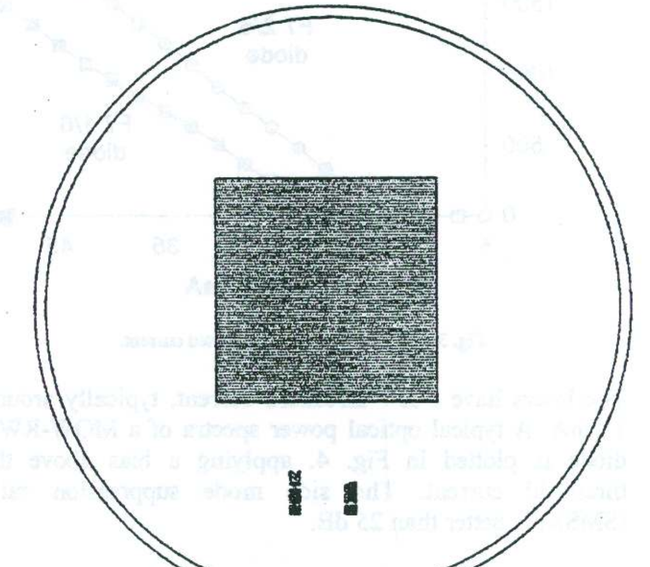

Fig. 9. Layout of the integrated unbalanced Mach-Zehnder interferometer.

The dimension of the realized component is 14 x 32 mm^2, and the radius of the integrated rings is approximately 6 mm. Two Y-junctions are also included in the shorter optical path of the interferometer to compensate the higher attenuation in the longer arm.

The technology of fabrication of the waveguide has been optimized for minimizing loss due to curvature. However, for the case of the device shown in Fig. 9, nearly 30 dB of total optical loss was measured. This was mainly due to the small designed bend radius of the rings. Further improvements are expected by using a bit increased ring radius. This is because bend losses decrease exponentially when increasing the bend radius [9].

The measured microwave frequency response of the global hybrid integrated system is presented in Fig. 10. In this experiment, the laser was directly modulated up to 6 GHz. A microwave rejection depth of about 15 dB was obtained at 1.9 GHz. Periodic characteristic of the microwave response is also observed in close agreement with the theoretical prediction (Eq.1). Unfortunately, due to the excessive loss of the realized optical device, the measured result was strongly corrupted by noise.

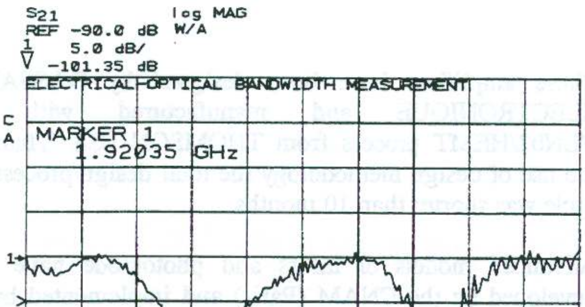

Fig. 10. Microwave frequency response of the integrated UMZI (using a w = 12µm channel width laser diode at I_{bias} = 40mA).

Conclusions

Hybrid integration of laser diode chips to integrated optical waveguides may find interesting applications in ultra-wideband signal processing (up to 100 GHz), telecommunications, radar or phased array antenna systems, where optical interconnections between microwave subsystems are needed [10].

The possibility of hybrid integration of a laser diode array on a glass substrate has been demonstrated. Direct butt-coupling of laser chip to a glass channel guide was realized showing an acceptable efficiency (around 25%). We also investigated the possibility to realize hybrid optoelectronic devices for microwave signal processing applications. Preliminary results were obtained by doing the hybridization of an integrated unbalanced Mach-Zehnder interferometer to a MQW-RWG laser chip. This hybrid device shows a microwave filtering response with a rejection depth of about 15 dB at 1.9 GHz.

Acknowledgments

The authors wish to thank Anh Ho Quoc for his help and Philippe Gérard for the development of the first prototype of the hybrid integrated system.

The work has been carried out within the framework of the project PROCOPE N° 94107, and was also founded by the TEMPRA program.

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